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Project 8.12b

SUPPLEMENTARY PRESSURE MEASUREMENTS
REPORT TO THE TEST DIRECTOR

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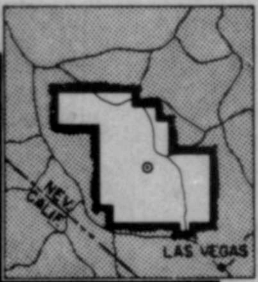

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OPERATION UPSHOT-KNOTHOLE

Project 8.12b

SUPPLEMENTARY PRESSURE MEASUREMENTS

REPORT TO THE TEST DIRECTOR

by

Vernon E. Benjamin

May 1955

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ABSTRACT

The purpose of this experiment was to check on the possibility that preshock pressures might be generated by sudden exposure of a surface to intense thermal irradiation, as from an air burst of an atomic weapon. Preshock pressures are defined as any change in the pressure datum, between weapon detonation time and main shock or precursor arrival time.

Test panels 10 ft by 10 ft were installed at 1500 ft and 3000 ft ranges from intended ground zero for Shots 9 and 10 of Operation UPSHOT-KNOTHOLE. Three panels at each location were faced with materials selected for their thermal properties. The panels were inclined toward the expected detonation points so substantially more thermal influence would be obtained on the test surfaces than on the surrounding ground. The ranges selected were outside the region of extremely high overpressures and very early shock arrival times.

The pressure datum was monitored at the center of each panel and also at a ground level control station at each range by sensitive, fast responding, David Taylor Model Basin capacitance type pressure gages.

No preshock activity was recorded on Shot 9. A sustained preshock record deflection, the equivalent of a positive overpressure of about 3 psi, was obtained on Shot 10 from a gage at the center of a panel faced with soil from Frenchman Flat. This panel was at a ground range of 1493 ft and had been subjected to a total thermal flux of 60 cal/cm^2 before the arrival of the main shock front. It appears that this might have been an actual pressure generated at the test panel but other factors related to the instrumentation preclude a positive conclusion on the basis of one isolated record.

FOREWORD

This report is one of the reports presenting the results of the 78 projects participating in the Military Effects Tests Program of Operation UPSHOT-KNOTHOLE, which included 11 test detonations. For readers interested in other pertinent test information, reference is made to WT-782, Summary Report of the Technical Director, Military Effects Program. This summary report includes the following information of possible general interest.

a. An over-all description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the 11 shots.

b. Compilation and correlation of all project results on the basic measurements of blast and shock, thermal radiation, and nuclear radiation.

c. Compilation and correlation of the various project results on weapons effects.

d. A summary of each project, including objectives and results.

e. A complete listing of all reports covering the Military Effects Tests Program.

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ACKNOWLEDGMENTS

The field operations covered in this report were carried out at the Nevada Proving Ground under the direction of the author by the following David Taylor Model Basin engineering staff members who also processed the data, made editorial comments, and otherwise assisted in the preparation of this report:

Mr. Charles W. Hoffman

Mr. Frank H. Kendall, Jr.

Mr. Fred B. Miller

Other members of the Instrumentation Division aided in preparing the equipment for this operation. The Public Works Department transported the equipment to and from the Nevada Proving Ground. The Technical Information Division processed the report.

The cooperation of LCDR Roger G. Preston, USN, Director, Program 8 and Lt. Robert M. Casson, USN, Assistant Director, Program 2, who shared the same office, was greatly appreciated. The assistance furnished by the Military Effects Group was gratefully received.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

This experiment was designed as a check on the possibility of the occurrence of preshock pressures at a surface exposed to intense thermal irradiation from a low height-of-burst nuclear weapon. A preshock pressure is defined as any local change in the air pressure level that occurs between weapon detonation time and the arrival of the main shock front or precursor.

There was general agreement, at the time this experiment was planned, that precursor formation, per se, was by the mechanism of propagation of a portion of a primary shock front at velocities in excess of the shock front velocity in a layer of intensely heated air near the ground. This test was designed to determine whether any other preshock phenomena might occur in advance of the precursor or the main shock front.

In order to carry out the experiment, panels faced with materials of different thermal properties were to be exposed to the air detonation of two nuclear weapons. Sensitive pressure gages were to be mounted at the centers of these panels which were to be inclined normal to the incident radiation. Pressure recordings were to be made over a time period to include weapon detonation and main shock arrival.

Groups of panels were to be located at two distances to give a spread of thermal intensities. A control gage was to be located at the surface of the ground at each range to compare the response at the panel surfaces with that for the natural surrounding terrain and to give a further spread in thermal intensities by virtue of a greater angle of incidence on the horizontal ground stations, compared to the inclined normal incidence panels. The instrumentation to be used had been

developed and used by the David Taylor Model Basin for pressure measurements on Operation TUMBLER.

1.2 EXPERIMENT DESIGN

1.2.1 Background on Preshock Phenomena

The blast pressure records and high speed rocket trail photography from Operation TUMBLER Shot 4, clearly indicated the existence of certain shock phenomena in advance of the main shock wave. Careful re-analysis of the photographs and pressure records from Operation BUSTER indicated the previously unobserved existence of similar precursor phenomena on Shots Charlie and Dog, and showed evidence of the possible existence of a precursor on Shot Easy. The precursor phenomena were also observed on GREENHOUSE Shots Dog and Easy.

Explanations for the formation of preshock pressures were compounded during Operation TUMBLER. [1,2] Shot 4 pressure observations along the blast line, and rocket trail photography along a line transverse to the blast line, indicated the presence of the precursor for ground ranges out to about 2000 ft. The precursor pressure at 2090 ft along the blast line had diminished to a few tenths of a psi. The maximum over-pressure at this range was 9.2 psi.

David Taylor Model Basin (DTMB) measurements [3] from TUMBLER Shot 4 however, indicated that a sizable precursor, approximately 3.0 psi, existed at a ground range of 2240 ft in an area that had been stabilized with blacktop road-building compound. Since, in general, asymmetrical pressure distribution prevailed on this shot a logical conclusion was that the thermal properties of the blacktop produced conditions favorable to the extension of the precursor region.

Explanations suggested for the precursor effect have included the thermal shock hypothesis and the hot-layer hypothesis, both of which are concisely summarized in refs (1) and (4). The hot layer or wave-guide theory has received general acceptance, and the DTMB TUMBLER Shot 4 records can be used as a basis for deducing that a layer of superheated air extended at a greater range over the black asphalt surface than it did over the Yucca Flat blast line in the T-7 area. In accordance with the theory, a portion of the reflected shock front is jetted out in advance of the main shock because of the higher velocity of propagation obtained in the layer of very hot air. The precursor is then related directly to the main shock but advanced in time and distance. By this theory the precursor originates at a range where the heated layer condition allows its velocity to exceed that of the parent shock front.

It is also possible that thermal shock results from the

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"popcorning" reaction of soil particles as a result of sudden application of radiant energy following bomb detonation. The water of crystallization in the soil particles is suddenly converted to steam. The resultant volumetric expansion and associated violent ejection of sand and dust particles may be thought of as a miniature explosion. If millions of these minute explosions occur simultaneously over a large area and continue over a period of time the integrated effect might result in an increase in the air pressure near the reacting surface. This thermal shock theory has not been generally accepted as an explanation for precursor formation. It was hoped that this experiment would help to answer questions as to the existence and significance of thermal shock pressures.

Attempts have been made to track the precursor to its source by observation of the pressure datum at or near ground zero for the period between bomb detonation and shock arrival time. Such experiments have either failed to show preshock pressures or if any apparent pressures were observed such signals were judged to be due to thermal effects on the gage or to unbalances set up in the instrumentation system by the severe electromagnetic transients associated with bomb detonations. It is believed by the author that in most cases such experimental gage setups could not have detected preshock pressures because thermal time lag factors delay the initiation of such phenomena until after the arrival of the incident shock. The pressure phenomena would be relatively small in respect to the main shock pressure and would be difficult to observe with instrumentation already recording the pressure of the shock front.

On Shot 9 of Operation UPSHOT-KNOTHOLE Sandia Corporation recorded apparent preshock pressures 5/ of about 0.4 psi maximum at a ground range of 840 ft and about 0.2 psi at 956 ft. At each range one gage was mounted at 2 ft elevation and one at 10 ft. The shock initiation times at the two levels for each range were simultaneous. The pressures are attributed to thermal radiation effects. It may be shown that the total amount of radiation received at the ground by the time of the peak apparent pressures was about 5 cal/cm^2 for the 840 ft range and 10 cal/cm^2 for the 956 ft range. Whether these thermal levels are sufficient to produce the observed change in air pressure has not been shown. It is noted however that the observed pressures are inversely proportional to the amount of thermal energy received at the ground by the time of the maximum excursion of the pressure recording system.

The record obtained by Sandia Corporation on Shot 10 at a ground range of 424 ft is of the precursor type. Whether it also contains a thermal shock component is not resolved since the arrival of the main shock front at 0.09+ sec obscures further observation of the development of any preshock part of the pressure trace.

1.2.2 Background on Experimental Technique

It was desired to study preshock phenomena in regions of lower overpressure and later shock arrival time than prevail near ground zero. Ranges of 1500 and 3000 ft were selected for this experiment. In order to obtain thermal intensities ordinarily experienced by surfaces closer to ground zero the thermal panels were mounted on the faces of aboveground bunkers at an inclination nominally normal to the incident thermal radiation.

1.2.3 Background on Instrumentation

The instrumentation employed by the DTMB on Operation TUMBLER and for this experiment on Operation UPSHOT-KNOTHOLE has adequate thermal shielding so that phantom pressure signals due to direct thermal effects on the pressure gages do not appear for thermal intensities encountered on Shots 9 and 10 at the selected ranges. The sensitivity of the instrumentation to the severe electromagnetic transient associated with bomb detonation was not determined during Operation TUMBLER since recording was initiated after detonation time. However, no long term disturbance to the measurement circuitry was noted on TUMBLER since the pressure reference data were stable before shock arrival time and repeated closely after the pressure cycle was completed. The pressure gages used during Operation UPSHOT-KNOTHOLE could detect pressure changes of the order of 0.1 psi. The same gages can be used for full scale pressures of the order of 75 psi by adjustment of the attenuators in the associated electronic circuitry.

1.2.4 Field Installation Plan

The experimental plan to carry out the objectives of this experiment was worked out in conference with the Technical Director, Military Effects Group, Armed Forces Special Weapons Project representatives, and DTMB personnel. It was decided that pressures would be monitored at the centers of 10 ft by 10 ft thermal panels which would be inclined toward the target detonation point to obtain high incident thermal flux. The panels would be located remotely enough from intended ground zero (IGZ) to be out of the very high overpressure region. Three test panels surfaced with materials of different thermal characteristics were to be instrumented at each of two ranges and a fourth gage with its supporting instrumentation was to be installed at each range at ground level for control and comparison purposes.

1.2.5 Thermal Panel Bunkers and Instrument Shelters

The gage station plan is shown in Fig. 1.1. Typical cross sections show the bunker elevation, the angle of inclination of the thermal panels and the location of the instrument shelters. The gage stations were grouped around two surveyed working points each 147 ft north of the main blast line on Frenchman Flat and at distances of 1500 ft and 3000 ft from IGZ, measured along the blast line. The designations for the two groups of stations were "A" and "B" respectively. The gages at the centers of the thermal panels at the "A" location were 3.8 ft above grade level and those at the "B" location were 4.4 ft above grade, by actual measurement.

Since the expected heights of burst for Shots 9 and 10 were 2400 ft and 500 ft respectively, a mean angle of inclination for the thermal panels was selected in respect to normal incidence of the thermal flux from each shot.

The instrumentation shelters were located behind and beneath the bunkers. These timber and plywood structures, 3 ft by 4 ft in section, extended in the ground 10 ft. Instruments were located at the bottom of each shelter in an "L" shaped offset to provide maximum blast and nuclear radiation protection.

The thermal panel support surfaces were made of 3/4 in. plywood over a timber framework. A 14 in. steel cylinder was installed at the center of each panel and recessed into the bunkers. A 3 in. conduit connected the cylinder to the instrument shelter. The open end of the cylinder received a face plate which supported the pressure gage body. The bunkers were built up with earth backfill to firmly support the panels. The sides of the bunkers were sandbagged for stability. Removable platforms were provided in the instrument shelter shafts so the upper sections of each shelter could be sandbagged to complete the blast protection for the instrumentation.

1.2.6 Thermal Panel Materials

Black ceramic tile, black asphalt roofing paper, and an adobe made from Frenchman lakebed soil were used as the thermal panel facing materials. The ceramic tile was selected as a thermally absorbing but non-reactive surface, the roofing paper as a thermally absorbing smoke-producing surface, and the adobe as a reflective but reactive ("pop-corning") surface. The panel for the ground level gage was the alluvial lakebed material, substantially the same as the fabricated adobe. Naval Material Laboratory 6/ tests of the thermal behavior of these materials showed the radiant absorptance (for 6000°K black-body radiation) to be

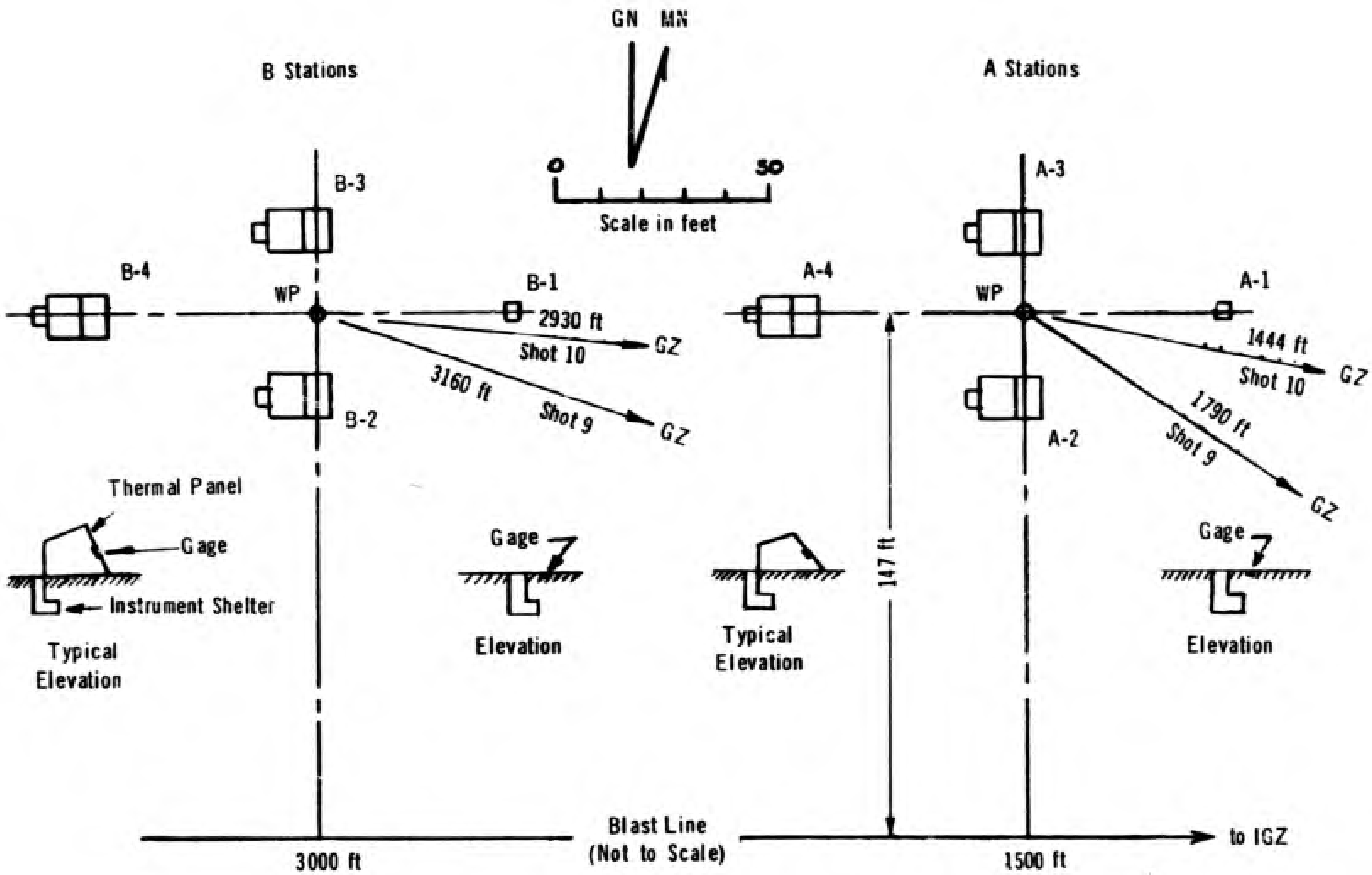

Fig. 1.1 Gage Station Plan

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0.93, 0.94, and 0.48 respectively for the black tile, the black asphalt roofing paper, and the adobe. The water content of the adobe as tested in the laboratory was 3.6 per cent. It is likely that the water content was slightly higher at the time of the field operations.

1.2.7 Thermal Panel Installation

Stations A-1 and B-1: The natural lakebed alluvial deposit provided the thermal panel around the ground level gages. The surface was graded, raked, tamped, sprinkled and allowed to dry.

Stations A-2 and B-2: The black ceramic tile was mounted over a groundcoat of concrete on metal lath. For Shot 9 the tile was fastened with Portland cement except for 24 tile on a removable center section around the gage which were attached to a backing board with mastic type adhesive. Figure 1.2 shows the completed thermal panel for Station B-2 before Shot 9. The gage is in place at the center of the removable section of tile. A steel disk temporarily protects the gage diaphragm and the removable section of tile has not been fastened down nor has the thermal shadow shield been placed above the gage at the stage of readiness shown. After Shot 9 and in preparation for Shot 10 all of the tile was replaced at Station A-2. The replacement tile was cemented with mastic type adhesive instead of Portland cement. The reason for this change in cements will be brought out in Chapter 2.

Stations A-3 and B-3: Figure 1.3 shows Station B-3 with the asphalt roofing paper nailed in place in preparation for Shot 9. Five layers of 65 lb roofing paper were used to make a covering 1/2 in. thick. For Shot 10 a new outer layer of 35 lb asphalt roofing paper was installed at each station.

Stations A-4 and B-4: The thermal panels were made from Frenchman lakebed soil mixed with water to a stiff mud consistency and plastered over metal lath to a thickness of about 1-1/2 in. The curing was controlled by occasional sprinklings during the first two days of drying, and by protection from the sun. A thin grout coat was finally worked into the surface to fill cracks that appeared during the drying. The same surfaces were used for Shot 10 with some minor patching after Shot 9. An edge of Station B-4 appears on the left in Fig. 1.3 and a closeup of the entire surface is shown in Fig. 1.4. The gage diaphragm had not been exposed or readied for test operations at the time the latter photograph was taken.

1.3 INSTRUMENTATION

The DTMB capacitance type pressure measuring instrumentation was used on this project to monitor preshock pressures at the thermal

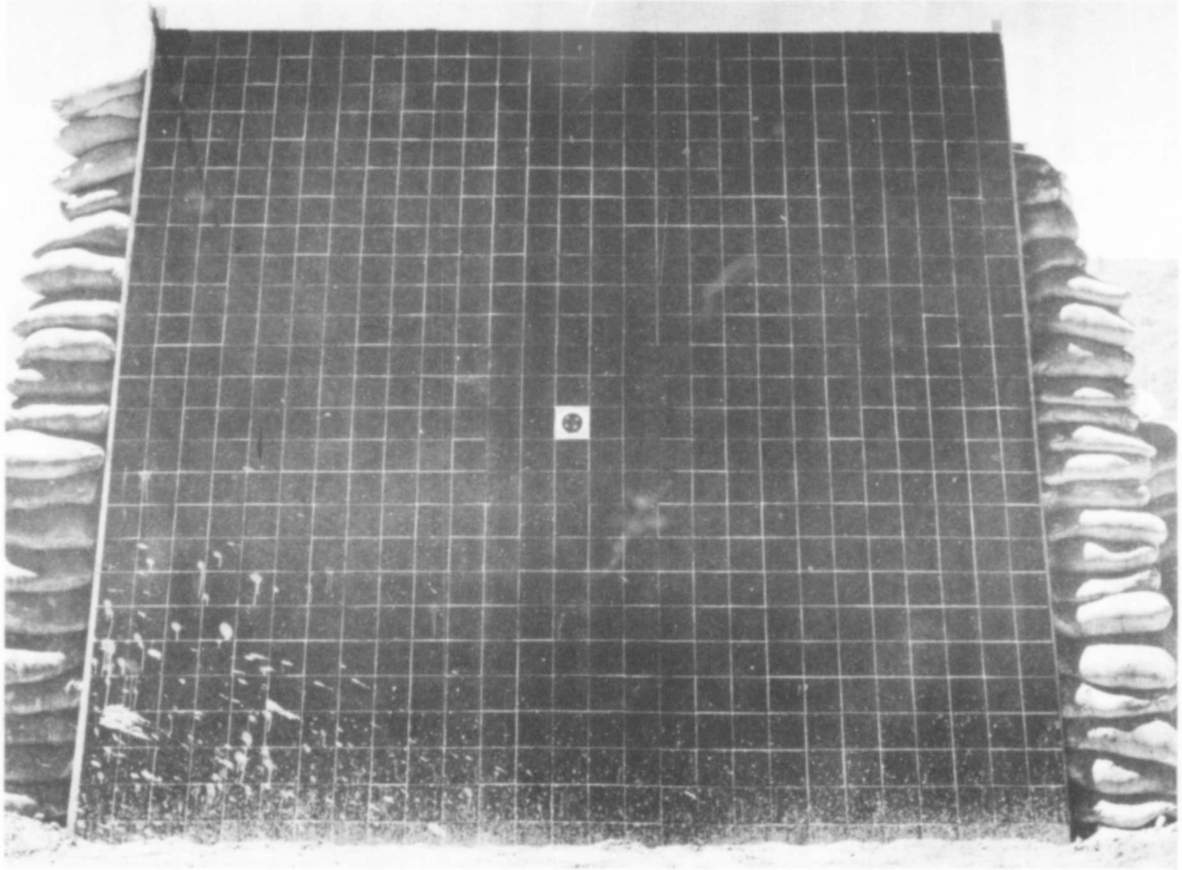

Fig. 1.2 Black Ceramic Tile Thermal Panel

The panel at Station B-2 is shown prior to Shot 9. The gage at the center of the panel is protected by a steel plate.

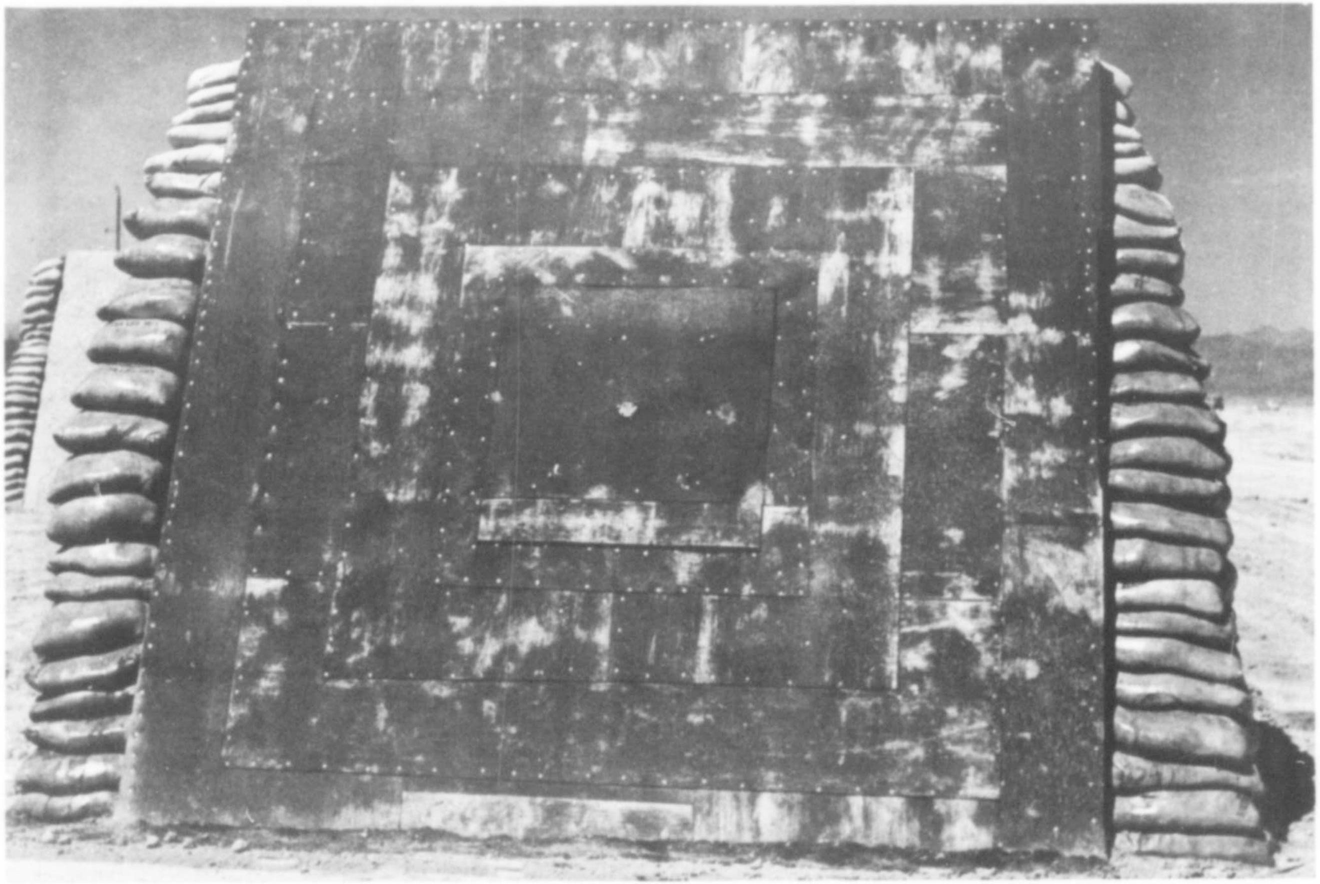

Fig. 1.3 Black Asphalt Roofing Paper Thermal Panel

The panel at Station B-3 is shown prior to Shot 9. The gage at the center of the panel is protected by a steel plate.

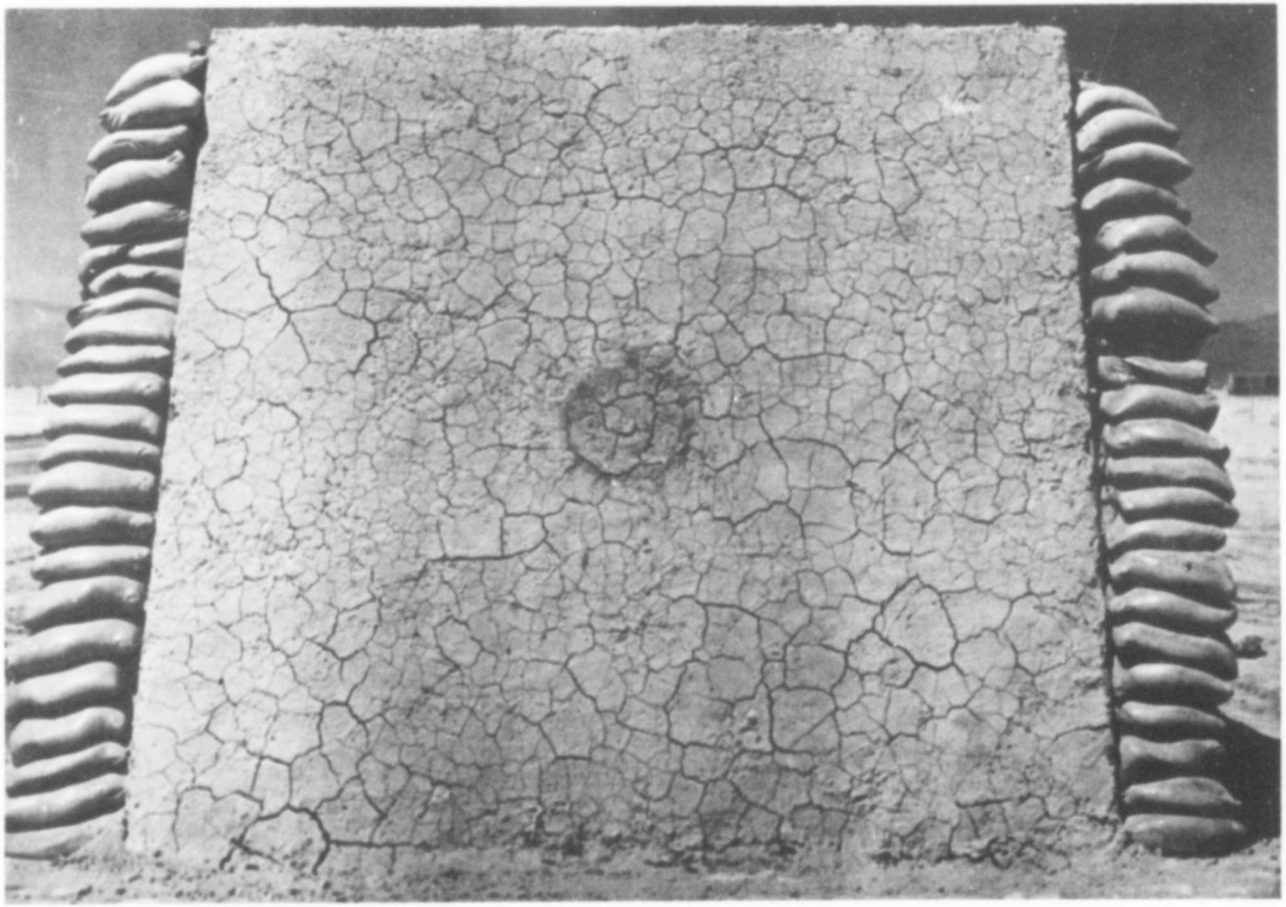

Fig. 1.4 Frenchman Flat Adobe Thermal Panel

The adobe plastered panel at Station B-4 is shown as prepared for Shot 9. The gage at the center has not been uncovered.

panels. This instrumentation system is completely described in ref (3). A complete, self-contained, locally powered, pressure recording installation was made at each gage station. The pressure transducer was a diaphragm type gage forming one arm of a special type of capacitance bridge. The capacitance of this arm varied in accordance with pressure changes on the diaphragm. The diaphragm was mounted in a gage head which was an integral part of a heavy brass gage body enclosing special doubly-resonant bridge circuitry and associated passive bridge elements. The natural frequency of the 3/16 in. diameter diaphragm was about 50,000 cps.

Cables connected the gage bridge circuits to the remote bridge-driving and capacitance-change sensing instrumentation. A power supply unit operating from a 24 volt aircraft-type storage battery and a incathode-ray-tube 16 mm streak film camera made up the rest of the instrumentation system. All of the instrument units except the battery were mounted in a shockproof rack within a dust tight, aluminum shipping and installation box.

The gages were capable of linear response to pressures up to about 75 psi and could withstand somewhat higher overpressures. With the gages used the recording system could be adjusted to a maximum sensitivity of the order of 5 psi full scale. The exact sensitivity depended primarily on individual diaphragm-stiffness and electrode spacing in each gage.

Figure 1.5 shows the mounting of a gage on the cover plate of the protective steel cylinder. The cylinder was in place at the center of the bunker. The gage head extended through the cover plate. The pressure sensitive diaphragm was flush with the surface of the thermal panel material.

The gage diaphragm was protected from dust, dirt, and thermal damage by a replaceable 1/8 in. thick Porex filter. Additional thermal shielding was provided by a circular shadow shield of heavy aluminum foil, 8 in. in diameter, which was suspended 6 in. above the gage by a light wire framework (see Fig. 2.3 for shadow shield detail).

Primary calibration of each pressure measuring system was achieved by applying a known static pressure to each gage after installation in the panels. The calibration apparatus is shown in use in Fig. 1.6.

In actual test use the electronic equipment was activated by a -30 min timing signal relay for preshot warmup, and the recording cameras were started by the closing of a -2.5 sec relay. The operation of the system was such that a pressure applied to the gage resulted in the impression of a corresponding d.c. voltage on the deflection plates of a small cathode ray tube in the camera unit. A photographic record was made of the position of the electron beam on the face of the tube with a 16 mm streak film camera. The average speed of the film was about

15 ft/sec and the total running time was about 6 sec. A timing signal was flashed on the film at 5 msec intervals. Automatic secondary electrical calibration of the system in terms of a known capacitance change previously directly related to the static pressure calibration occurred shortly after the film drive motor was started. After the pressure phenomena was recorded the equipment was automatically turned off and all circuits were deenergized.

Figure 1.5 Attachment of Gage Head to Protective Drum Cover

The pressure gage head is being mounted to the back of the cover of the protective drum which is seen installed in the bunker. The gage diaphragm extends through the cover.

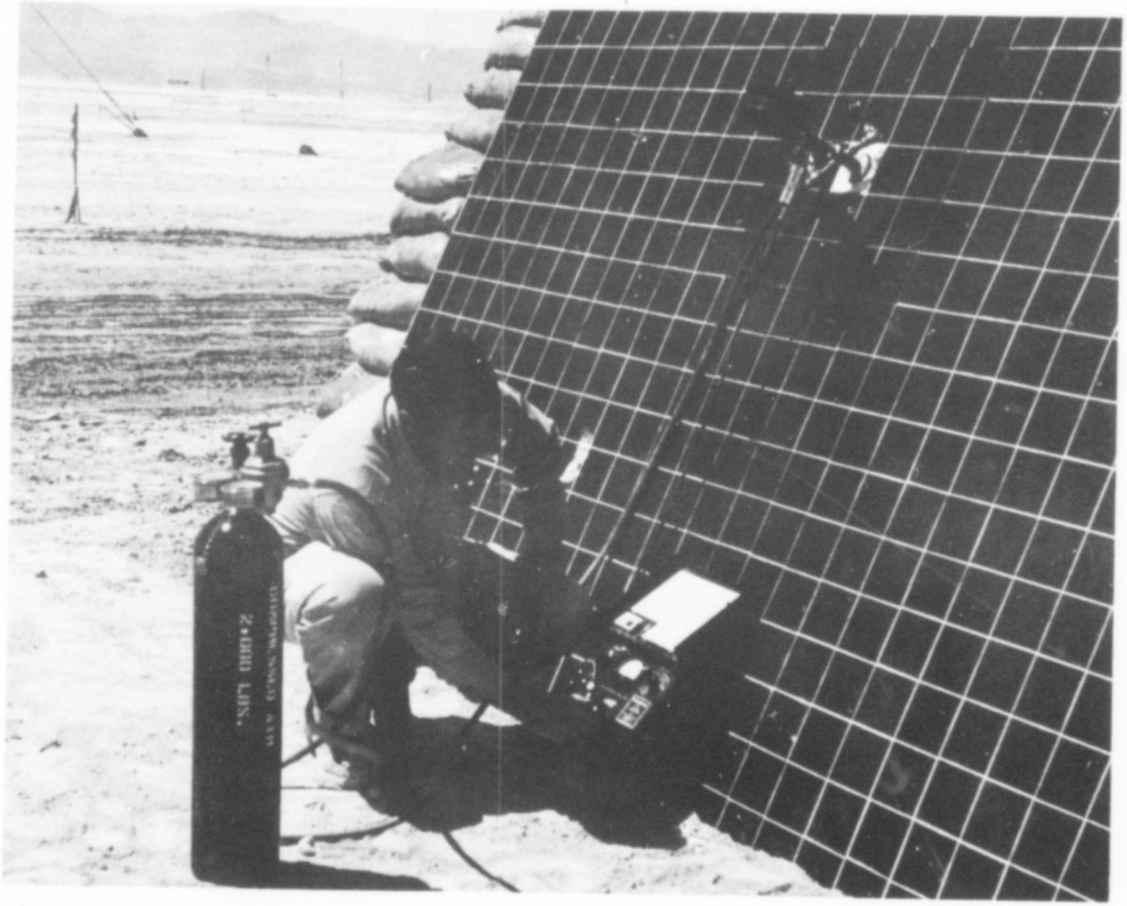

Fig. 1.6 Calibration of Pressure Measuring System

Primary calibrations were made by applying measured static pressures to the gage diaphragms. Synthetic calibrations were incorporated in the automatic electrical circuitry.

CHAPTER 2

OBSERVATIONS AND RESULTS

2.1 POSTSHOT OBSERVATION OF THERMAL PANELS

Pertinent observations of the physical conditions of the thermal panels, the bunkers and the instrumentation shelters after Shots 9 and 10 are reported here. Structurally all underground instrumentation shelters held satisfactorily although supplemental vertical shoring was used. No parts of the instrumentation systems were damaged or became inoperative due to electromagnetic, thermal, or blast effects. The thermal shadow shields and the Porex filters over the gages were designed as one-shot protective devices and were replaced between shots. The conditions at each gage station are discussed in the sections below.

2.1.1 Station A-1 Ground Level Gage

The positive impulse from Shot 9 settled the backfill around the instrument shelter and thereby compacted it well for Shot 10.

2.1.2 Station A-2 Black Ceramic Tile Thermal Panel

On Shot 9 about 15 per cent of the tile popped completely off the Portland cement groundcoat. The black surface of all the tile was crazed. Sub-surface explosions of entrapped moisture from pre-cementing soaking produced shallow craters over half of the entire panel surface with the exception of the 24 squares in the center section around the gage. These tile were cemented with a mastic adhesive and were not soaked in water before setting. Figure 2.1 shows a view of Station A-2 following Shot 9. (The middle section has been removed for access to the gage.)

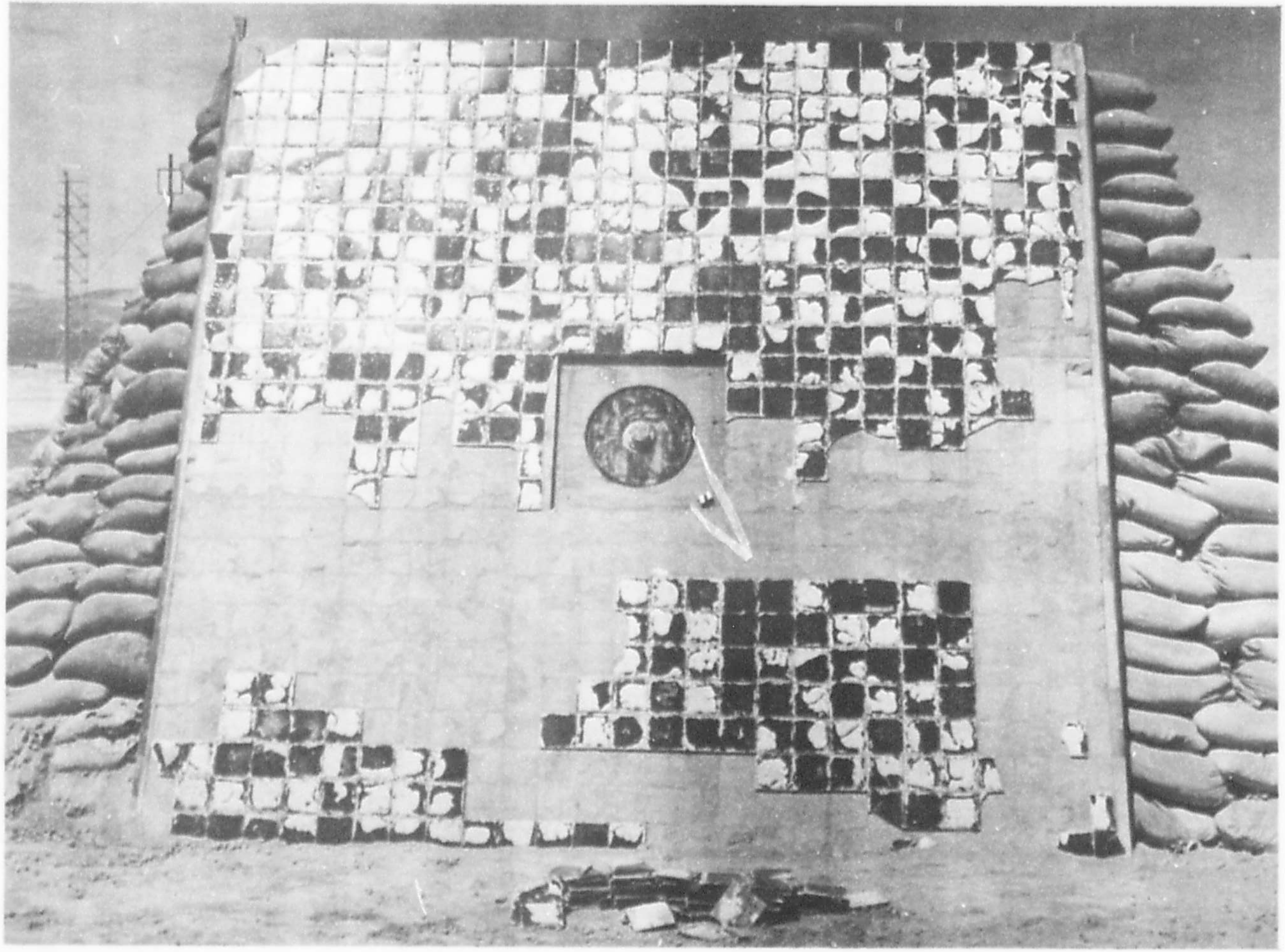

Fig. 2.1 Postshot 9 Condition of Thermal Panel, Station A-2

In preparation for Shot 10, tile was replaced on this panel with mastic adhesive. Postshot 10 observations indicate that the entire surface of the tile to a depth of about half the thickness of the black coating had melted, foamed, and bubbled into lava-like droplets which flowed down the panel slope about 1/4 in. Dust kicked up by the blast was imbedded in the molten outer surface which finally solidified into a dirty buff colored, rough, stucco-like finish. No evidence of sub-surface explosions from within the tile was found in contrast to the postshot 9 conditions with moisture laden tile.

2.1.3 Station A-3, Black Asphalt Roofing Panel

The outer layer of the black asphalt roofing paper was almost completely removed by combined burning and blast from Shot 9 but the next layer showed no signs of thermal damage. Recovered samples of the outer layer showed that the exposed surface had been heated enough to soften the asphalt surface so that it became impregnated with dust churned up by the blast wave.

Shot 10 effects removed the asphalt paper completely from the plywood backing panel. Bits of paper were scattered for 1000 ft to the rear of the station. All samples recovered had shrunk to about half their original thickness, probably due to the boiling out of the tar products. The plywood backing panel was not burned or charred, which indicates that at least some of the paper protected the plywood during all of the intense thermal activity.

2.1.4 Station A-4, Adobe Panel

The adobe panel suffered less damage than the other two panels at the "A" Station on Shot 9. About 95 per cent of the surface was left intact and ready for reuse on the next shot.

Shot 10 effects completely removed the adobe surface but the metal lath and plywood backing showed no thermal damage. This would indicate that the adobe was removed in the main by blast effects. All of the "A" Station bunkers were pushed back by the severe horizontal dynamic loadings imposed by Shot 10. A skip-loader had to be used to uncover the instrument shelters for removal of the records and instruments. Figure 2.2 shows the condition of Station A-4 after Shot 10.

2.1.5 Station B-1, Ground Level Gage

On Shot 9 the entire instrument shelter and the surrounding backfill was pushed into the ground about 8 in. presumably by the impulse from the blast. This had no influence on the records or equipment

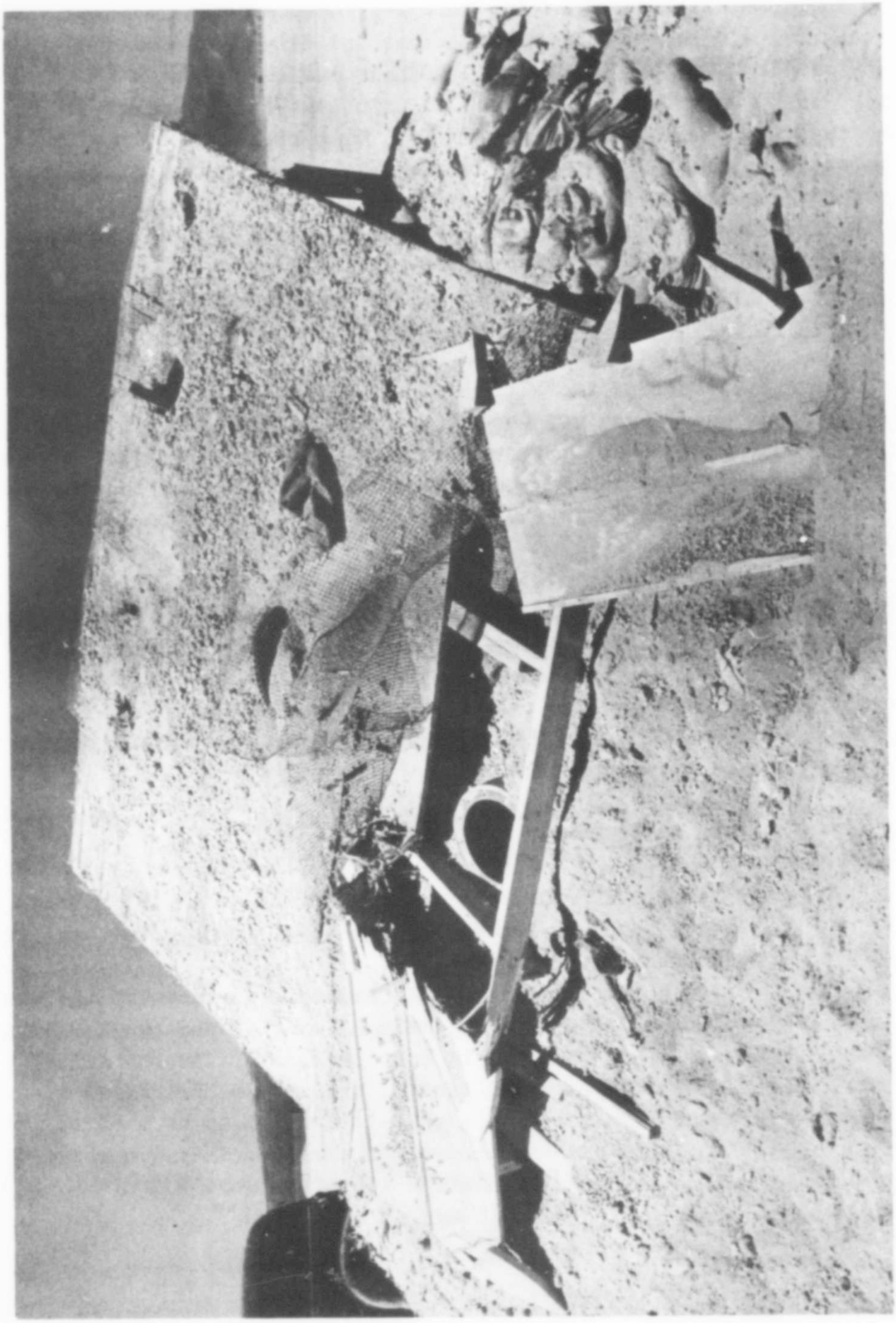

Fig. 2.2 Postshot 10 Condition of Thermal Panel, Station A-4

and required no readjustment for Shot 10.

Shot 10 produced little thermal or blast damage at any of the "B" stations.

2.1.6 Station B-2, Black Ceramic Tile Panel

About 95 per cent of the tile surface had exploded in the same manner as at Station A-2 except that the craters were not so deep. The tile in the mastic cemented center section around the gage did not suffer any surface eruption and this is again attributed to the moisture-free condition of the tile.

2.1.7 Station B-3, Black Asphalt Roofing Panel

Shot 9 heated the outer surface of the asphalt paper sufficiently to cause small drops of asphalt to flow. Heat was not transmitted through the outer layer of paper enough to fuse or bond it to the second layer.

2.1.8 Station B-4, Adobe Panel

After Shot 9 the adobe surface at this station was 95 per cent intact. No changes in the surface condition could be detected by close visual examination.

2.2 EFFECTIVENESS OF THERMAL SHADOW SHIELDS

The effectiveness of the thermal shadow shields used to protect the gages from direct exposure to the thermal pulse is brought out vividly in Fig. 2.3 which is a close-up photograph of the removable center panel of the mastic-cemented black ceramic tile from Station B-2 after Shot 9. The shadow shield wire framework is held in the same position it occupied for Shot 9. A remnant of the aluminum foil is still attached to the lower part of the outer circle of the frame. The panel is shown in the orientation it had relative to target zero.

A random crazed pattern is noted on the tile surface for areas that were exposed to direct irradiation but the area that was shielded is unmarked. A distinct boundary is formed by the radial fault lines resulting from the severe stress discontinuity tangential to the periphery of the shadowed area. The shadow is "off center" because the angle of inclination of the panel was a mean value between normal incidence for two different heights of burst and because GZ and IGZ were not coincident.

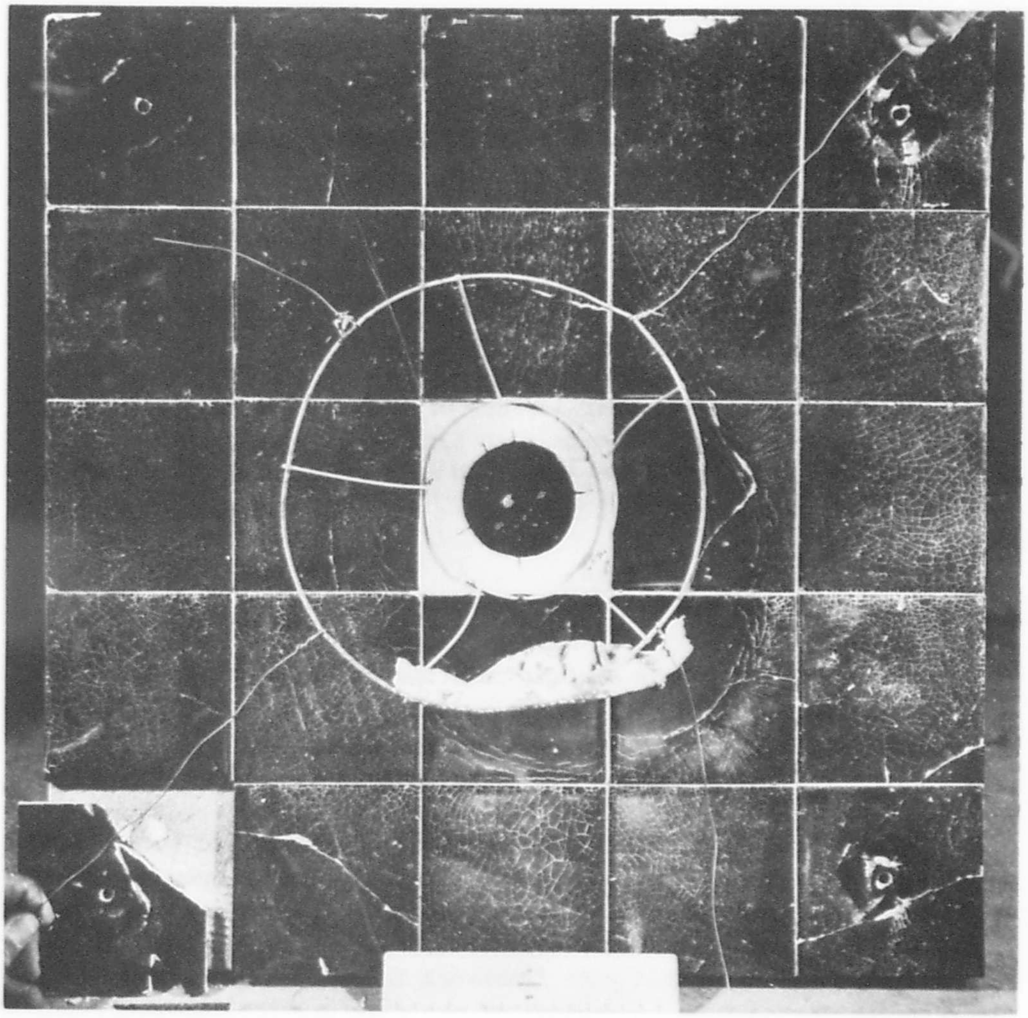

Fig. 2.3 Removable Section of Tile and Shadow Shield

The shadow shield framework is shown in the position it occupied during Shot 9 over the removable section of tile around the gage at Station B-2. A remnant of the aluminum foil is still attached to the top of the frame.

2.3 RESULTS AND DISCUSSION

The pressure-time records obtained at the eight gage stations on Shots 9 and 10 are analyzed with respect to any apparent pressure signals that occurred between the time of weapon detonation and the arrival of the blast shock front at each station. Pertinent records are reproduced and results are tabulated.

2.3.1 Shot 9 Results "A" Stations

The pressure gage recordings at Stations A-1, A-2, A-3, and A-4 are presented in Fig. 2.4. The pressure traces are plotted on a time base representing elapsed time from weapon detonation. Pressure amplitudes are scaled on the left hand ordinate and ground ranges are scaled on the right. The datum pressure level was zero psig for each station from detonation time to shock arrival time, therefore the preshock portions of the records are not shown. The shock front pressure traces are terminated in arrows to indicate continuation to higher overpressure levels that were not of interest in regard to the objectives of this project. The total thermal energy received at each panel prior to the arrival of the main shock wave is shown on the graph. The cosine law correction has been applied to account for the angle of incidence of the thermal flux on each surface and the curves of percentage of thermal energy delivered as a function of time, from ref (7), have been used to arrive at the amount of energy incident on the test surfaces up to the arrival time of the shock fronts.

As stated above, no pressure changes were detected during the preshock period. The thermal intensity vs time curve 7/ shows that about half of the thermal energy had been delivered to the test surfaces before the arrival of the shock front. In fact, the peak of the thermal intensity, 175 cal/cm^2, occurred at 0.18 sec. As explained in Appendix B any thermal reaction of the lakebed sand, which formed the test panels for A-1 and A-4, should have begun within 0.2 sec of the thermal peak, or about 0.4 sec from detonation time. No preshock pressures resulted from "popcorning" of the sand and no pressure changes of any other origin were detected at any of the thermal panels on Shot 9.

A time of arrival line is drawn from which the average horizontal velocity of the advancing shock front can be determined. The time intercepts for the scaled ground range on the right hand ordinate gives an average velocity of 2000 ft/sec over the 76 ft span of the "A" Stations.

The Mach stem was observed to have formed at about 800 ft 7/ and was probably 5 ft high at the range of the "A" Stations. Since the gages were all lower than this the shock front shape would be expected

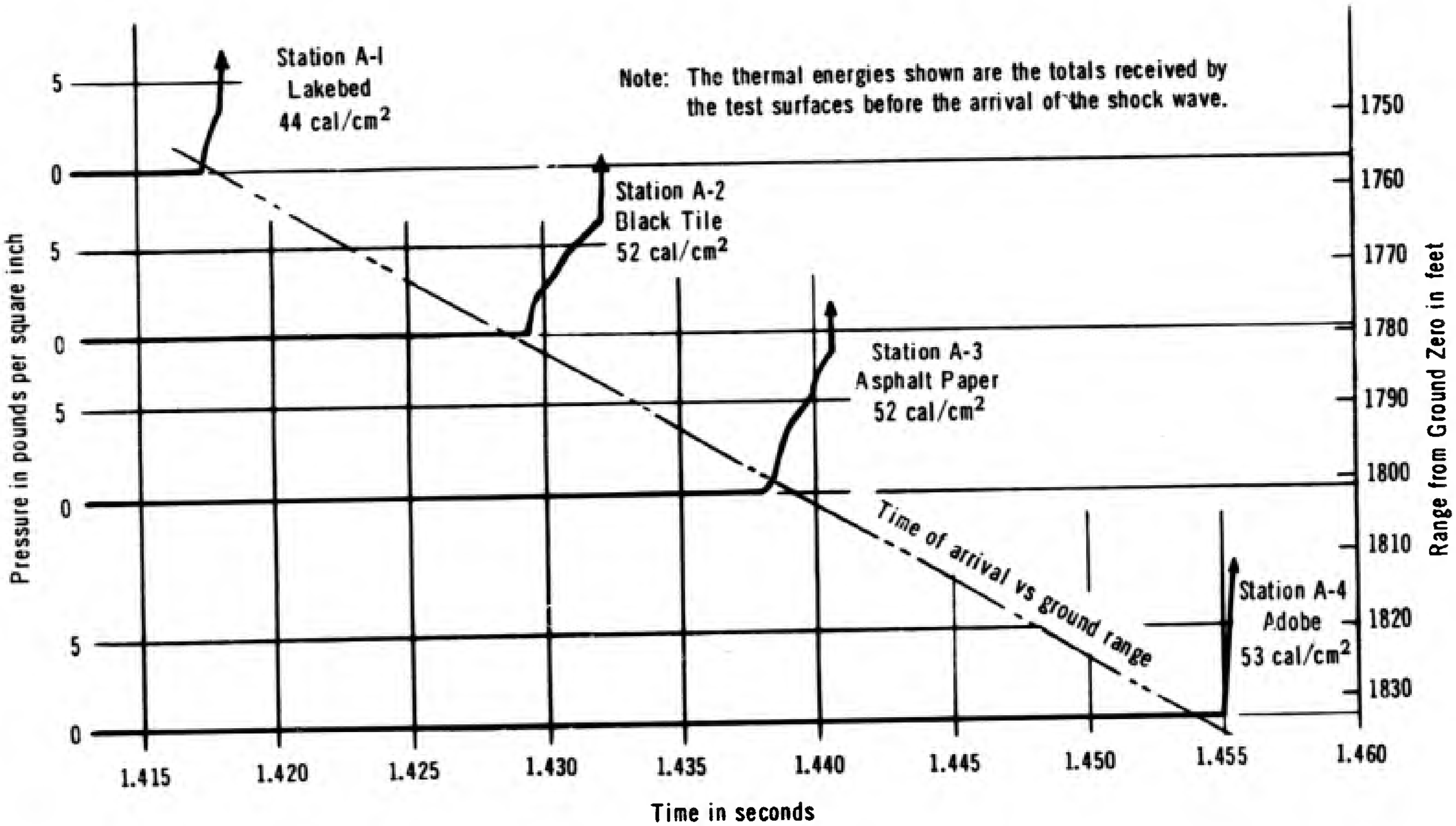

Fig. 2.4 Shock Front Waveforms, Shot 9

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to be abrupt. The modification that existed in the shock front, as may be deduced from the shape of the pressure trace, may be attributed to a combination of factors associated with turbulent friction at the solid interface between ground and air and to temperature gradients in the dust laden air near the ground.

2.3.2 Shot 9 Results, "B" Stations

The pressure records obtained at the "B" stations, mean range of 3160 ft, are not reproduced since they were all uniformly abrupt in waveform with no evidence of any preshock signals. The horizontal component of the shock velocity at that range was determined to be 1460 ft/sec.

2.3.3 Shot 10 Results, "A" Stations

The pressure gage readings obtained on Shot 10 at Stations A-1, A-2, A-3, and A-4 are reproduced in Fig. 2.5 for the portion of the record including the precursor type shock front. Overpressure amplitude is plotted against time from weapon detonation. Ground ranges are scaled on the right hand ordinate; the pressure reference datum for each station coincides with the ground range for that station. Terminating arrows on the pressure traces indicate continuation of the record into a time domain not of interest to this project.

All records showed a slow rising precursor type shock front with a slope of about 1 psi/msec. The precursor blended more or less smoothly into the sustained positive phase overpressure wave recorded at the ground level reference gage, 1400 ft range. The average pressure from this record was about 11.5 psi. Pressure amplitudes on the inclined panels were greater because of reflection factors. As in Shot 9, Station A-4 was nearly in line with A-2 in respect to the advancing shock front and the pressure wave at A-4 was distorted at the time the influence of A-2 reached the rear station, 0.39 sec. The slope of the time of arrival line, drawn through points of precursor arrival at each station, is 2240 ft/sec. This is the average horizontal component of shock front velocity over the 94 ft span of the "A" stations.

The complete record for the A-1 and A-2 gages contains no signal that can be construed as a preshock pressure although the electromagnetic transient displaced the record sharply in a negative pressure direction at detonation time. The exponential recovery to the pressure reference level required 0.13 sec and 0.20 sec respectively.

The record for Station A-3, the black asphalt roofing paper panel, showed anomalous behavior during the part of the trace following detonation until just before the arrival of the precursor. Almost

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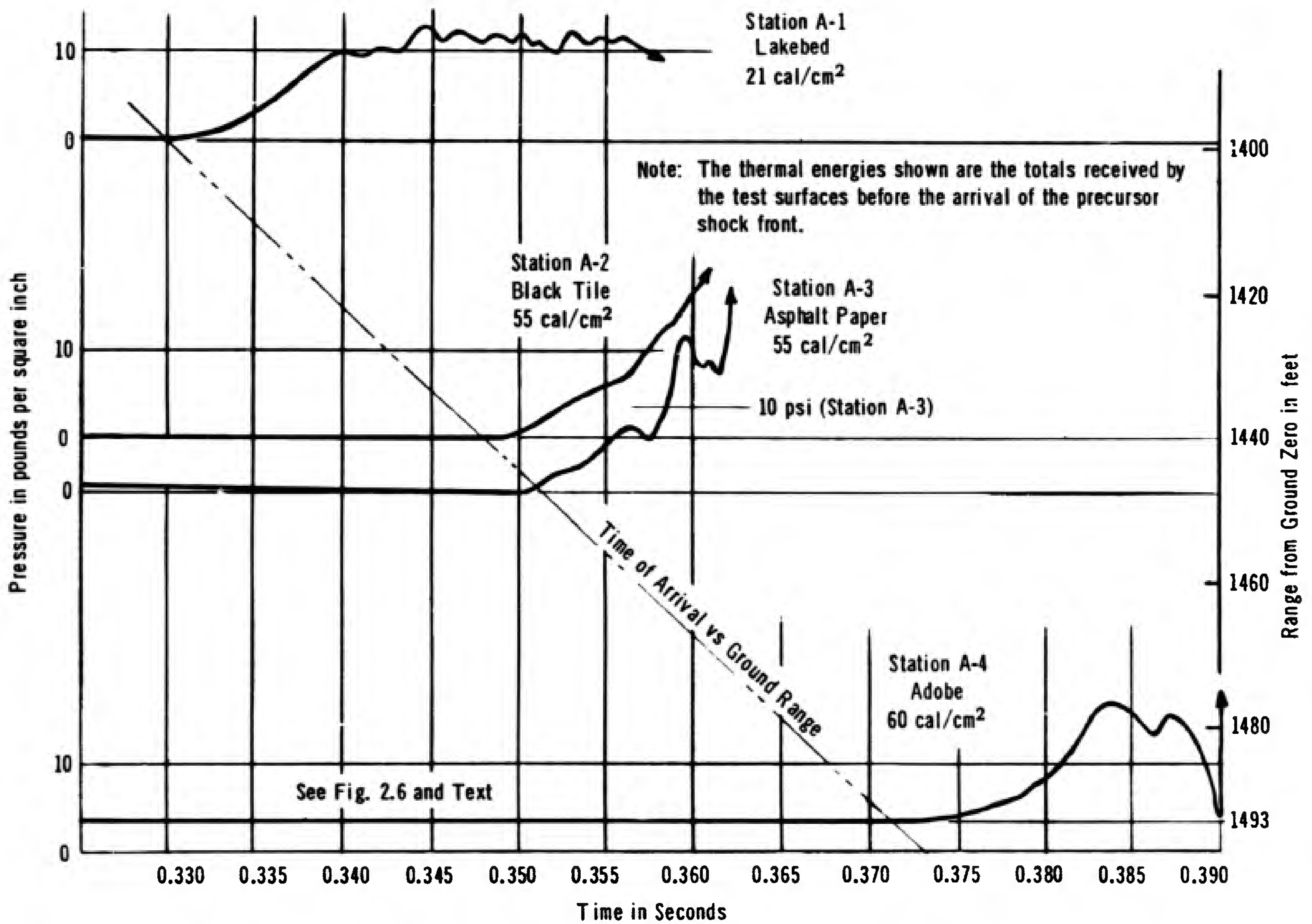

Fig. 2.5 Preshock Signals and Shock Front Waveforms, Shot 10

immediately following the sharp negative electromagnetically-produced transient the pressure trace deflected rapidly in the direction of positive pressure to a high off-scale value. The trace returned to the zero pressure datum just before the arrival of the precursor shock front. Because the initial rise of the recorded signal occurs before the rise of the thermal pulse associated with bomb detonation, the recorded-trace could not have been a pressure or a response of the gage resulting from the thermal action. The gage responded correctly to the shock front.

The electromagnetic transient influences on the pressure measuring instrumentation must be evaluated to obtain information from which conclusions as to the meaning of recorded excursions in the preshock time domain may be formulated. A complete study of each detonation-time transient for Shots 9 and 10, as recorded, is presented in Appendix A. Information is extracted from Appendix A in the following discussion of the record obtained at Station A-4 on Shot 10.

In Fig. 2.5 the pressure trace for Station A-4 is seen to be about 3 psi above the zero reference datum prior to the arrival of the precursor type shock front. The complete time record from this gage is shown in Fig. 2.6. The first 0.1 sec of the record has been adjusted to remove the probable effect of the initial transient signal. From a start at about 0.05 sec, the pressure trace rises gradually to a maximum value of 3.5 psi and holds nearly uniform at this pressure over the period of 0.175 to 0.275 sec. Then there is a gradual decrease in amplitude to about 2.7 psi before the arrival of the precursor shock front. The shape and amplitude of the precursor wave compare favorably with the general shape of the precursor traces for the other "A" stations. The average ground level pressure for this range was about 14.7 psi. 7/

Whether the recorded trace represents an actual pressure that existed on panel A-4, or some unpredictable behavior of the measurement system resulting from the electromagnetic transient, cannot be resolved from the one record. From laboratory evaluation tests of the measurement system it is reasonably certain that thermal influences, as such, on the gage could not have caused a record excursion in the direction of positive pressure. A blowtorch flame directed on the Porex filter over a gage diaphragm is known to produce a deflection of the record in the direction of negative pressure but only after several seconds of exposure. In the field installation the gages were protected with Porex filters and a thermal shadow shield. The shadow shield provided protection at least during the early part of the thermal pulse on Shot 10. It is believed that the recorded excursion cannot be the result of thermal influences on the gage.

The possibility that the record obtained at Station A-4 might

actually be a locally generated pressure can be discussed. We can assume that the occurrence of a pressure at an isolated surface, such as the inclined adobe panel, is the result of reactions set up in the surface material and in the air layer near the surface as a result of intense thermal irradiance on that surface. We will have to consider if the factors known justify this assumption. First, can we differentiate between a thermal shock and a precursor effect, since the presence of a heated layer of air is one of the criteria for precursor occurrence? The answer is yes if the location of the test surface and its layer of locally heated air is far enough removed in time from the shock wave resulting from weapon detonation so a precursor does not have time to propagate from the shock wave to the test panel before locally generated shocks appear.

A further study of the known factors can be made with the aid of Fig. 2.6 in which the approximate curve for the thermal pulse from Shot 10 is drawn to the same time base as the pressure record from Station A-4 which is shown in its entirety from detonation time to precursor wave arrival time. The thermal pulse used in the NML test 6/ of the lakebed material is also shown on the graph. The amplitude scale for this pulse is the same as the amplitude scale for the Shot 10 thermal curve. The maximum intensity of the thermal pulse on Shot 10 occurred at about 0.12 sec and about 50 per cent of the total thermal energy of 111 cal/cm^2 was received at the inclined thermal panels before the arrival of the precursor wave.

The reaction of the Frenchman Flat lakebed material (adobe) to the NML test pulse is presented in detail in Appendix B, but the pertinent results as related to the Shot 10 thermal pulse are summarized here. The color motion pictures taken of the reaction of the three different thermal materials used in the panels during the laboratory exposure to a carbon arc source show that the lakebed material reacts much differently from either the black ceramic tile or the black asphalt roofing paper. (Fig. B-1 shows selected frames of these pictures.) A "popcorning" of fine sand particles starts after the adobe surface has been exposed to the source for about 0.20 sec. This action continues as a uniform violent eruption of minute sand particles and fine dust for the entire duration of the test exposure and terminates almost instantly after the shutter closes and cuts off the thermal source. Particles of sand are expelled radially outward from the exposed area with velocities such that they carry from 6 to 10 in. The NML reported that the eruption was accompanied by a crackling noise. Post-test observations of the surface showed that a crater 1/8 in. deep and about 5/8 in. in diameter had been eroded by the thermal action.

It is suggested that the integration of the multitudinous miniature explosions caused by the sudden transformation of the water of

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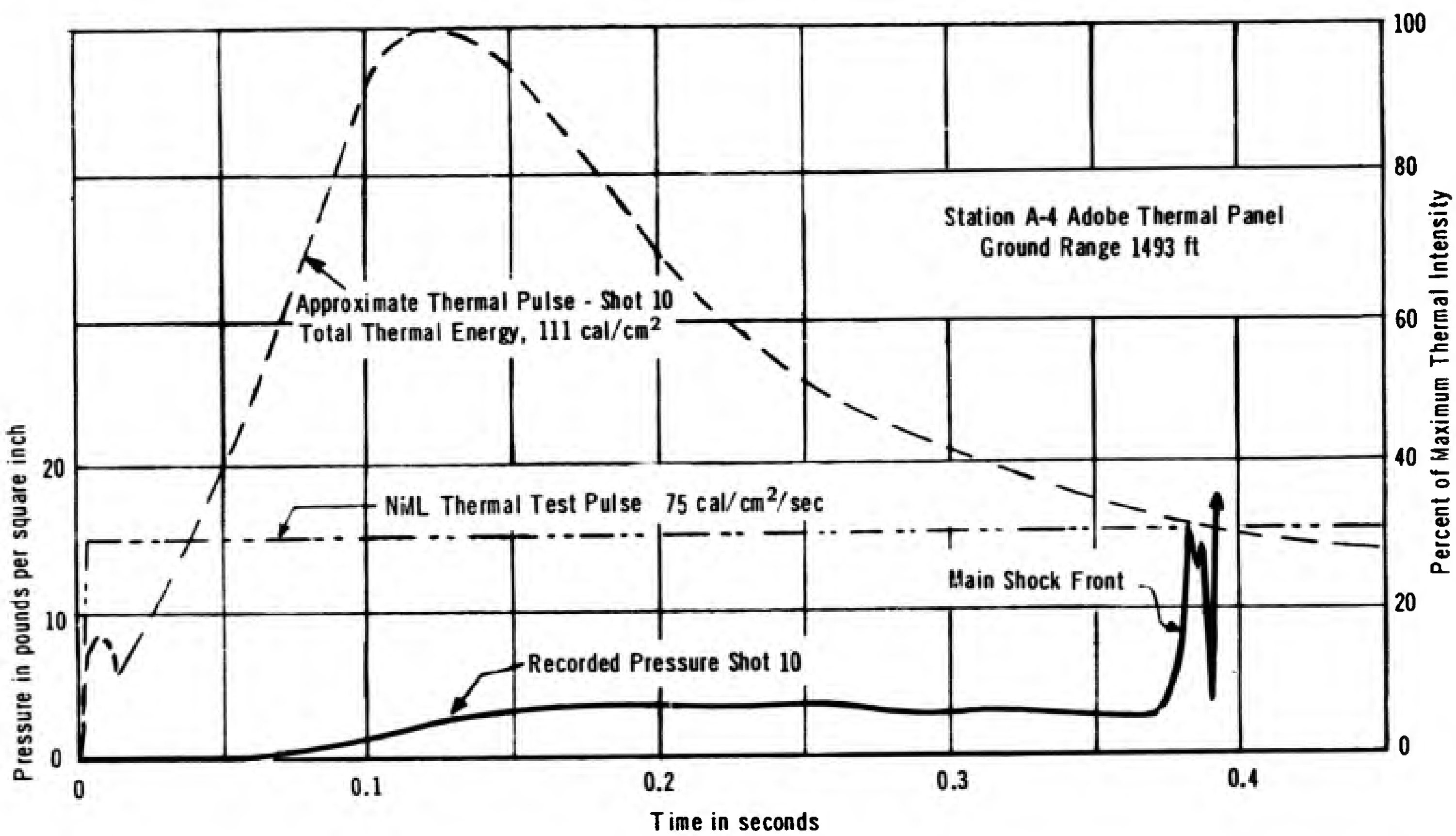

Fig. 2.6 - Station A-4 Record for Shot 10

crystallization into steam produces a positive overpressure which is almost a steady uniform value as long as the thermal energy continues to reach the surface at a uniform rate. The "popcorning" activity is nearly uniform because almost all of the nonreflected thermal energy is used up in converting the water of crystallization into steam. As the exposed surface erodes, fresh material is continuously exposed to the source. Measurements of temperature just below the exposed surface during the NML test showed that the material did not increase in temperature as would have been the case if the non-reflected energy were not utilized at the surface.

From Fig. 2.6 one can make a direct comparison between the energy input for the laboratory test of the lakebed material and for the field test on Shot 10. Approximately the same total amount of energy had been received at each surface by 0.005 sec elapsed time After this the Shot 10 energy input was greater although the actual amount of energy received at the thermal panel might have been reduced by the dust cloud kicked up from ground surfaces in front of the panel. Thus it would be expected that the results observed during the laboratory tests simulated very closely the reactions during Shot 10. Pressure was not measured during the laboratory tests, and the source of the activity was so small that pressure detection might have been difficult.

2.3.4 Shot 10 Results, "B" Stations

The records from the "B" stations are not reproduced since, as for Shot 9, the waveforms are all abrupt and no preshock signals, other than the expected short duration electromagnetic transients, were recorded. The horizontal component of shock velocity for the mean range of 2930 ft was 1200 ft/sec based on the times of arrival at the four stations in this group.

2.3.5 Summary of Results Shots 9 and 10

The numerical data obtained from Shots 9 and 10 from the eight gage stations used on each shot are summarized in Table 2.1.

TABLE 2.1 Summary of Results

Gage Station	Thermal Panel Material	G.R. (ft)	S.R. (ft)	Total Flux cal/cm^2	Angle to Surface Normal	Total Thermal Flux on Surface cal/cm^2	Thermal Flux Received before Arrival of Main Shock Wave cal/cm^2	Shock Arrival Time (sec)
SHOT 9								
A-1	Lakebed	1756	2960	81	53.4°	59	44	1.418
A-2	Black Tile	1779	3000	81	30.4°	70	52	1.429
A-3	Asphalt Paper	1801	3000	81	30.4°	70	52	1.438
A-4	Adobe	1832	3050	81	30.4°	70	53	1.455
B-1	Lakebed	3123	3940	50	37.4°	40	33	2.169
B-2	Black Tile	3154	3980	50	20.4°	47	39	2.184
B-3	Asphalt Paper	3166	3980	50	20.4°	47	39	2.196
B-4	Adobe	3209	4030	50	20.4°	47	40	2.222
SHOT 10								
A-1	Lakebed	1399	1470	120	69.4°	42	21	0.330
A-2	Black Tile	1440	1514	120	21.9°	111	55	0.348
A-3	Asphalt Paper	1448	1516	120	21.9°	111	55	0.350
A-4	Adobe	1493	1565	120	21.9°	111	60	0.371
B-1	Lakebed	2885	2918	40	79.7°	7	5	1.324
B-2	Concrete	2928	2961	40	14.5°	39	30	1.367
B-3	Asphalt Paper	2932	2963	40	14.5°	39	30	1.368
B-4	Adobe	2980	3012	40	14.5°	39	31	1.403

CHAPTER 3

CONCLUSIONS

3.1 SHOT 9 CONCLUSIONS

No preshock pressures were observed on Shot 9 at any of the "A" or "B" Stations. Data from several other projects show the presence of a Mach stem closer to ground zero than the 1800 ft range of the "A" stations. The pressure records from the four gage installations in the 1800 ft range indicate that the Mach stem was distorted near the ground, i.e., bent in the forward direction. This close to the ground distortion may be attributed to turbulent friction at the solid interface between ground and air and to temperature gradients in the thermal layer near the ground.

The shock arrival time at 1800 ft was 1.439 sec and the horizontal component of velocity, calculated from arrival times at successive stations in this range, was 2000 ft/sec. The steep fronted shock wave arrived at 4000 ft at 2.202 sec. The horizontal component of velocity, as calculated from arrival times at successive stations in this range, was 1460 ft/sec.

3.2 SHOT 10 CONCLUSIONS

The shock front at the "A" stations, 1400 ft from ground zero, was of the precursor type with a slope of 1 psi/msec. The precursor blended smoothly into the early positive overpressure phase which averaged about 11.5 psi at ground level. The measurement instrumentation for Station A-4, the inclined panel faced with natural Frenchman Flat adobe, produced an amplitude vs time record that might be construed to be a thermally generated and sustained local shock. The evidence and information that leads the author to believe that a locally generated shock

was produced is not sufficient to warrant a positive conclusion. The NML irradiation tests show clearly the explosive nature of the reaction of the lakebed material when exposed to intense and sustained thermal energy. Were it not for the possibility that the recorded sustained positive preshock overpressure at Station A-4 might be an amplitude deflection produced in the measurement instrumentation by an extended influence of the detonation time electromagnetic transient signal, the validity of the recorded phenomena could be supported. As it is, the one isolated record, by itself, is insufficient evidence for a conclusion.

3.3 INSTRUMENTATION CONCLUSIONS

The DTMB capacitance type self-contained pressure measuring instrumentation operated satisfactorily. No thermal, nuclear, or shock induced disturbances other than pressure signals were observed in the photographic records after the effects of the electromagnetic transient subsided. In general, this transient is short and is predictable as to size and duration from one test to another. However, anomalous results obtained from one record on Shot 10, Station A-3, make it necessary to suspect the validity of an apparent preshock pressure recorded on another channel, Station A-4, on the same shot. A special instrumentation modification test on Shot 10 showed that the electromagnetic transient effect can be attenuated in the pressure instrumentation system by improved magnetic shielding of the gage head (see Appendix A).

3.4 CONCLUSIONS ON THERMAL PANEL MATERIALS

The choice of thermal panel materials and the location of the panels for this experiment were generally satisfactory. The lakebed adobe used on two of the inclined panels duplicated the properties of the lakebed very closely. The black ceramic tile exploded internally when subjected to high thermal irradiation because of entrapped water remaining from the pre-application soaking. The substitution of black asphalt roofing paper in place of blacktop roadbuilding compound was necessitated by difficulties encountered in placing the blacktop on the inclined surface. It is felt that the blacktop material would have produced more information than was obtained with the roofing paper.

CHAPTER 4

RECOMMENDATIONS

4.1 GENERAL

The pressure measuring instrumentation used in this experiment has frequency resolution capabilities and broad full-scale sensitivity adjustments that make it particularly useful in obtaining detailed amplitude time studies of shock front waveforms. There is no ringing due to shock excitation as might occur with improperly damped low frequency devices. These characteristics make the system most useful for studies involving turbulent shock front patterns, local pressure generations, time phase studies of shock front and reflected waves and for operational evaluation of shock loading on aircraft where the velocity of the shock front is modified by the relative velocity of the aircraft.

Because of the unusual possibilities of this rugged equipment it is recommended that wherever possible consideration be given to further field use and evaluation of this system. The influence of the detonation time electromagnetic transient on the instrumentation system should be given further study.

4.2. THERMAL PANEL RECOMMENDATIONS

If this type of experiment is conducted again it is recommended that a natural soil mixture be used again as a thermal panel material. The thermal properties of the material could be modified by spraying the surface with a penetrating coating of asphalt or non-reactive dark dye. It is recommended that panels be oriented normal to the incident thermal flux. The shape of the panels should be triangular instead of square to simplify the problems of providing a solid earth backfill for support of all parts of the panel. The thermal panels should be

deployed at ranges to produce total thermal energies of between 30 and 80 cal/cm^2 on the inclined surfaces before the predicted arrival of the shock wave. Panels should be separated far enough from one another so pressure pattern interference does not result from proximity effects.

It would seem desirable to install several pressure gages in each panel not only for cross check purposes but to provide more complete data in respect to general blast phenomena. The shape of the shock front close to the ground could be studied from pressure time information at several gage heights in the panel, pressure reflection factors could be evaluated, and more general comparison could be made with blast line data.

APPENDIX A

ELECTROMAGNETIC TRANSIENT EFFECT ON INSTRUMENTATION

The preshock signal recorded at Station A-4 on Shot 10 might possibly be attributed to an instrumentation unbalance introduced by electromagnetic effects at the time of weapon detonation. A detailed study is presented of the waveforms generated in all the recording channels as a result of these sharp transient signals.

The exact process whereby the electromagnetic signal is coupled into the electronic equipment is not understood. It is believed the process can be likened to the action of either a magnetic or dielectric amplifier circuit, or both. In general the response of each of the separate pressure recording systems was consistent from shot to shot. This seems to indicate that consistent polarization effects might be attributed to all detonations, or that polarization cannot be assigned as a property of the detonation but that one part of the gage-bridge circuit is consistently more vulnerable than the rest.

The relative waveforms of the transient signals for all gage channels on Shots 9 and 10 are shown in Fig. A.1. The transients are sketched to indicate fairly accurately the waveforms actually observed on the 16 mm film record. The amplitudes of the excursions are only approximate since the initial departure, at the instant of weapon detonation time, often went off scale. The time at which each transient returned to the pre-detonation datum is indicated on each sketch.

Notes A through E on Fig. A.1 explain certain peculiarities that influenced waveshapes or have a bearing on comparison of the difference in response for the two shots. Note A points out a slight shift in the zero datum for Station A-2 on Shot 9. This shift represents 0.6 psi in the direction of the initial transient excursion, which in this case was the direction of negative pressure. Note B calls attention to the unusual response of Station A-3 on Shot 10,

attributed to unknown effects introduced by the electromagnetic signal. It should be observed that this gage was the only one, out of the eight in use, where the direction of the initial transient excursion reversed between the two shots. Furthermore it was the only one in which the time of return of the trace to the zero datum was less on Shot 10 than on Shot 9 with the exception of those indicated by Notes D and E for which satisfactory explanations exist. As near as can be determined the gage head at Station A-3 and the cylinder cover on which the head was mounted were rotated 180° from the Shot 9 position after the Porex filter was changed in preparation for Shot 10. This might be of significance in respect to electromagnetic polarization effects.

Note D calls attention to a definite change in the waveform that was obtained as a result of a deliberate experimental procedure on Shot 10 at Station B-1. All gage heads were mounted on the inside of the covers of heavy steel drums as shown in Fig. 1.5 in the main text. These covers were normally bolted to the drums with a rubber gasket insert for waterproofing. In preparation for Shot 10 the rubber gasket was removed at Station B-1 with the thought in mind that the effective air gap in the magnetic shielding circuit would be reduced and better shielding would be obtained. The result is apparent from observation of the difference in transient waveform for the two shots. On Shot 10 the response of the system to the sudden transient was slowed down, as evidenced by the slower rise time and the rounded peak. Since the disturbance to the system was less severe the initial pressure datum was recovered sooner than would be predicted by the average time increase factor of about 5 for Shot 10 over Shot 9. It is apparent from all of the transient records that the electromagnetic effects at both the A and B stations were much more severe on Shot 10 than on Shot 9. Thus, the reduction in system response obtained by the field modification described above indicates that a thorough job of magnetic shielding with high grade magnetic materials might minimize the transient disturbance problem in this type of instrumentation.

Note E: The amplifier gain was reduced on this channel. The amplitude and time duration of the electromagnetic disturbance was accordingly reduced.

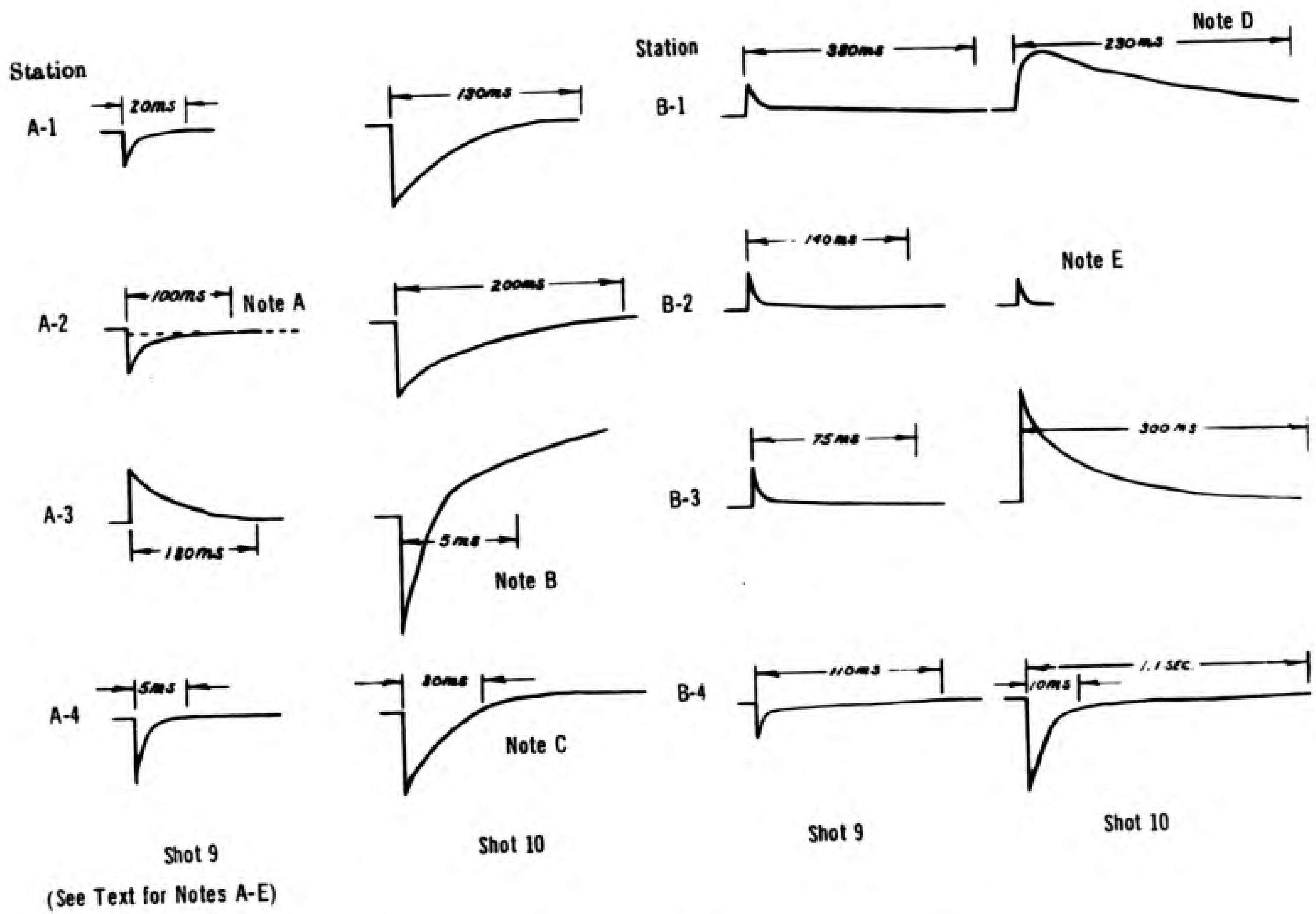

Fig. A.1 Detonation-Time Transient Signals

APPENDIX B

LABORATORY TESTS OF THERMAL PANEL MATERIALS

The Naval Material Laboratory (NML) carried out extensive thermal tests 6/ of the thermal panel materials used by Project 8.12b, following the completion of the field operations. Samples of the three panel materials were subjected to a laboratory source of thermal energy of 75 cal/cm^2/sec for 1.5 sec. A mechanical shutter was used to control the length of exposure so the pulse shape was effectively square.

The radiation absorptance (for 6000°K black-body radiation) for the black asphalt roofing paper, the black ceramic tile, and the Frenchman Flat adobe was determined by NML to be 0.94, 0.93, and 0.48 respectively. The water content of the adobe at the time of the laboratory test was 3.6 per cent. Other information was obtained during the tests by measurement of the temperature of the air above each sample, by measurement of the temperature of the material just below the exposed surfaces, and from color motion pictures during the tests.

The motion pictures have been studied carefully and selected frames from the film are reproduced in Fig. B.1. The time sequences read from top to bottom in each column. The columns are, left to right, black asphalt roofing paper, black ceramic tile, and Frenchman Flat adobe. The photographic records were analyzed directly from the original color transparency and from Fig. B.1.

Black Asphalt Roofing Paper The first four frames in Fig. B.1 show a progressively increasing smoking and burning action. After the closing of the shutter at 1.5 sec the activity decreased slowly. No unusual local surface action that might be interpreted as a pressure could be observed in either the stills shown or in the original motion picture film. The NML reported that a dense cloud of black smoke and flaky particles associated with the flame rose to the 12 ft high ceiling of the laboratory.

Black Ceramic Tile The dry tile specimen showed very little reaction as a result of the exposure to the carbon arc thermal source. A small amount of blue smoke was evolved; the fifth picture shows the ejection of two small particles from the surface of the specimen. After the shutter closed, surface smoking died down slowly. The temperature of the specimen was measured 1/32 in. beneath the exposed surface. The increase in temperature was 4°C at 1 sec and 140°C at 4 sec.

Frenchman Flat Adobe The sample of Frenchman lakebed adobe reacted much differently from the other two materials tested at NML. "Popcorning" of surface material began at about 0.2 sec after the initiation of exposure and was characterized by a violent eruption of sand particles and fine dust, with considerable velocity, radially from the exposed area. Particles were expelled for distances up to 10 in. with an almost uniform intensity until the shutter closed. A small wisp of smoke due to combustion of organic material, drifted upward but is a minor part of the total reaction at the surface. Almost as soon as the shutter closed all surface activity ceased. The NML reported that the ejection of particles was accompanied by a crackling noise, and that as a result of the exposure a crater about 5/8 in. in diameter and 1/8 in. deep was eroded in the surface.

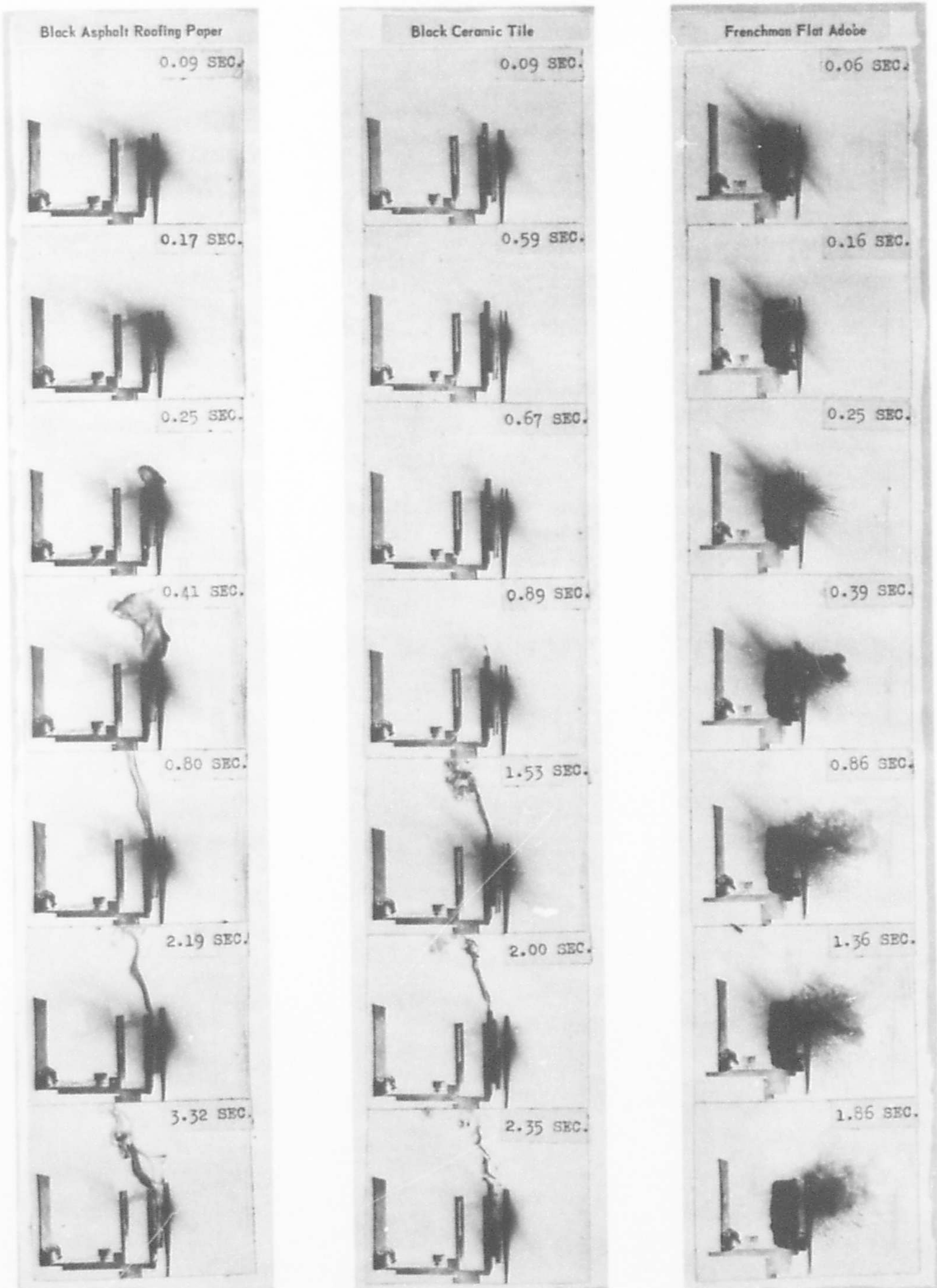

Fig. B.1 NML Test of Thermal Panel Materials

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20 President, Board #1, Headquarters, Continental Army Command, Ft. Bragg, N.C.
21 President, Board #2, Headquarters, Continental Army Command, Ft. Knox, Ky.
22 President, Board #3, Headquarters, Continental Army Command, Ft. Benning, Ga.
23 President, Board #4, Headquarters, Continental Army Command, Ft. Bliss, Tex.
24 Commanding General, U.S. Army Caribbean, Ft. Amador, C.Z. ATTN: Cml. Off.
25- 26 Commander-in-Chief, Far East Command, APO 500, c/o PM, San Francisco, Calif. ATTN: ACofS, J-3
27- 28 Commanding General, U.S. Army Europe, APO 403, c/o PM, New York, N.Y. ATTN: OPOT Div., Combat Dev. Br.
29- 30 Commandant, Command and General Staff College, Ft. Leavenworth, Kan. ATTN: ALLLS(AS)
31 Commandant, The Artillery and Guided Missile School, Ft. Sill, Okla.
32 Secretary, The Antiaircraft Artillery and Guided Missile School, Ft. Bliss, Texas. ATTN: Lt. Col. Albert D. Epley, Dept. of Tactics and Combined Arms
33 Commanding General, Medical Field Service School, Brooke Army Medical Center, Ft. Sam Houston, Tex.
34 Director, Special Weapons Development Office, Ft. Bliss, Tex. ATTN: Lt. Arthur Jaskierny
35 Commandant, Army Medical Service Graduate School, Walter Reed Army Medical Center, Washington 25, D.C.
36 Superintendent, U.S. Military Academy, West Point, N.Y. ATTN: Prof. of Ordnance
37 Commandant, Chemical Corps School, Chemical Corps Training Command, Ft. McClellan, Ala.
38 Commanding General, Research and Engineering Command, Army Chemical Center, Md. ATTN: Deputy for RW and Non-Toxic Material
39- 40 Commanding General, Aberdeen Proving Grounds, Md. (inner envelope) ATTN: RD Control Officer (for Director, Ballistics Research Laboratory)
41- 43 Commanding General, The Engineer Center, Ft. Belvoir, Va. ATTN: Asst. Commandant, Engineer School
44 Commanding Officer, Engineer Research and Development Laboratory, Ft. Belvoir, Va. ATTN: Chief, Technical Intelligence Branch
45 Commanding Officer, Picatinny Arsenal, Dover, N.J. ATTN: ORDBB-TK
46 Commanding Officer, Army Medical Research Laboratory, Ft. Knox, Ky.
47- 48 Commanding Officer, Chemical Corps Chemical and Radiological Laboratory, Army Chemical Center, Md. ATTN: Tech. Library
49 Commanding Officer, Transportation R&D Station, Ft. Eustis, Va.
50 Director, Technical Documents Center, Evans Signal Laboratory, Belmar, N.J.
51 Director, Waterways Experiment Station, PO Box 631, Vicksburg, Miss. ATTN: Library
52 Director, Armed Forces Institute of Pathology, 7th and Independence Avenue, S.W., Washington 25, D.C.
53 Director, Operations Research Office, Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase, Md., Washington 15, D.C. ATTN: Library
Commanding Officer, Signal Corps Engineering Laboratory, Ft. Monmouth, N.J.
54- 60 Technical Information Service, Oak Ridge, Tenn. (Surplus)

NAVY ACTIVITIES

61- 62 Chief of Naval Operations, D/N, Washington 25, D.C. ATTN: OP-36
63 Chief of Naval Operations, D/N, Washington 25, D.C. ATTN: OP-03EG
64 Director of Naval Intelligence, D/N, Washington 25, D.C. ATTN: OP-922V
65 Chief, Bureau of Medicine and Surgery, D/N, Washington 25, D.C. ATTN: Special Weapons Defense Div.
66 Chief, Bureau of Ordnance, D/N, Washington 25, D.C.
67 Chief, Bureau of Ships, D/N, Washington 25, D.C. ATTN: Code 348
68 Chief, Bureau of Yards and Docks, D/N, Washington 25, D.C. ATTN: D-440
69 Chief, Bureau of Supplies and Accounts, D/N, Washington 25, D.C.
70-71 Chief, Bureau of Aeronautics, D/N, Washington 25, D.C.
72 Chief of Naval Research, Department of the Navy Washington 25, D.C. ATTN: LT(jg) F. McKee, USN
73 Commander-in-Chief, U.S. Pacific Fleet, Fleet Post Office, San Francisco, Calif.
74 Commander-in-Chief, U.S. Atlantic Fleet, U.S. Naval Base, Norfolk 11, Va.
75- 78 Commandant, U.S. Marine Corps, Washington 25, D.C. ATTN: Code A03H
79 President, U.S. Naval War College, Newport, R.I.
80 Superintendent, U.S. Naval Postgraduate School, Monterey, Calif.
81 Commanding Officer, U.S. Naval Schools Command, U.S. Naval Station, Treasure Island, San Francisco, Calif.
82 Commanding Officer, U.S. Fleet Training Center, Naval Base, Norfolk 11, Va. ATTN: Special Weapons School
83- 84 Commanding Officer, U.S. Fleet Training Center, Naval Station, San Diego 36, Calif. ATTN: (SPWP School)
85 Commanding Officer, Air Development Squadron 5, VX-5, U.S. Naval Air Station, Moffett Field, Calif.
86 Commanding Officer, U.S. Naval Damage Control Training Center, Naval Base, Philadelphia 12, Pa. ATTN: ABC Defense Course
87 Commanding Officer, U.S. Naval Unit, Chemical Corps School, Army Chemical Training Center, Ft. McClellan, Ala.
88 Commander, U.S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: EE
89 Commander, U.S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: EH
90 Commander, U.S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: R
91 Commander, U.S. Naval Ordnance Test Station, Inyokern, China Lake, Calif.
92 Officer-in-Charge, U.S. Naval Civil Engineering Res. and Evaluation Lab., U.S. Naval Construction Battalion Center, Port Hueneme, Calif. ATTN: Code 753
93 Commanding Officer, U.S. Naval Medical Research Inst., National Naval Medical Center, Bethesda 14, Md.

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94 Director, U.S. Naval Research Laboratory, Washington 25, D.C. ATTN: Code 2029
95 Commanding Officer and Director, U.S. Navy Electronics Laboratory, San Diego 52, Calif. ATTN: Code 4223
96-97 Commanding Officer, U.S. Naval Radiological Defense Laboratory, San Francisco 24, Calif. ATTN: Technical Information Division
98 Director, Naval Air Experimental Station, Air Material Center, U.S. Naval Base, Philadelphia, Penn.
99-100 Commanding Officer and Director, David W. Taylor Model Basin, Washington 7, D.C. ATTN: Library
101 Commander, U.S. Naval Air Development Center, Johnsville, Pa.
102 Director, Office of Naval Research Branch Office, 1000 Geary St., San Francisco, Calif.
103-109 Technical Information Service, Oak Ridge, Tenn. (Surplus)

AIR FORCE ACTIVITIES

110 Asst. for Atomic Energy, Headquarters, USAF, Washington 25, D.C. ATTN: DCS/O
111 Director of Operations, Headquarters, USAF, Washington 25, D.C. ATTN: Operations Analysis
112 Director of Plans, Headquarters, USAF, Washington 25, D.C. ATTN: War Plans Div.
113 Director of Research and Development, Headquarters, USAF, Washington 25, D.C. ATTN: Combat Components Div.
114-115 Director of Intelligence, Headquarters, USAF, Washington 25, D.C. ATTN: AFOIN-IB2
116 The Surgeon General, Headquarters, USAF, Washington 25, D.C. ATTN: Bio. Def. Br., Pre. Med. Div.
117 Deputy Chief of Staff, Intelligence, Headquarters, U.S. Air Forces Europe, APO 633, c/o PM, New York, N.Y. ATTN: Directorate of Air Targets
118 Commander, 497th Reconnaissance Technical Squadron (Augmented), APO 633, c/o PM, New York, N.Y.
119 Commander, Far East Air Forces, APO 925, c/o PM, San Francisco, Calif.
120 Commander-in-Chief, Strategic Air Command, Offutt Air Force Base, Omaha, Nebraska. ATTN: Special Weapons Branch, Inspection Div., Inspector General
121 Commander, Tactical Air Command, Langley AFB, Va. ATTN: Documents Security Branch
122 Commander, Air Defense Command, Ent AFB, Colo.
123-124 Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, O. ATTN: WCRRN, Blast Effects Research
125 Commander, Air Training Command, Scott AFB, Belleville, Ill. ATTN: DCS/O GTP
126 Commander, Air Research and Development Command, PO Box 1395, Baltimore, Md. ATTN: RDDN
127 Commander, Air Proving Ground Command, Eglin AFB, Fla. ATTN: AG/TRB
128-129 Director, Air University Library, Maxwell AFB, Ala.
130-137 Commander, Flying Training Air Force, Waco, Tex. ATTN: Director of Observer Training
138 Commander, Crew Training Air Force, Randolph Field, Tex. ATTN: 2GTS, DCS/O
139 Commander, Headquarters, Technical Training Air Force, Gulfport, Miss. ATTN: TA&D
140-141 Commandant, Air Force School of Aviation Medicine, Randolph AFB, Tex.
142-147 Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, O. ATTN: WCOSI
148-149 Commander, Air Force Cambridge Research Center, 230 Albany Street, Cambridge 39, Mass. ATTN: CRQST-2
150-152 Commander, Air Force Special Weapons Center, Kirtland AFB, N. Mex. ATTN: Library
153 Commandant, USAF Institute of Technology, Wright-Patterson AFB, Dayton, O. ATTN: Resident College
154 Commander, Lowry AFB, Denver, Colo. ATTN: Department of Armament Training
155 Commander, 1009th Special Weapons Squadron, Headquarters, USAF, Washington 25, D.C.
156-157 The RAND Corporation, 1700 Main Street, Santa Monica, Calif. ATTN: Nuclear Energy Division
158 Commander, Second Air Force, Barksdale AFB, Louisiana. ATTN: Operations Anal. Office
159 Commander, Eighth Air Force, Westover AFB, Mass. ATTN: Operations Anal. Office
160 Commander, Fifteenth Air Force, March AFB, Calif. ATTN: Operations Anal. Office
161-167 Technical Information Service, Oak Ridge, Tenn. (Surplus)

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

168 Asst. Secretary of Defense, Research and Development, D/D, Washington 25, D.C. ATTN: Tech. Library
169 U.S. Documents Officer, Office of the U.S. National Military Representative - SHAPE, APO 55, New York, New York
170 Director, Weapons Systems Evaluation Group, OSD, Rm 2E1006, Pentagon, Washington 25, D.C.
171 Armed Services Explosives Safety Board, D/D, Building T-7, Gravelly Point, Washington 25, D.C.
172 Commandant, Armed Forces Staff College, Norfolk 11, Va. ATTN: Secretary
173-178 Commanding General, Field Command, Armed Forces Special Weapons Project, PO Box 5100, Albuquerque, N. Mex.
179-180 Commanding General, Field Command, Armed Forces, Special Weapons Project, PO Box 5100, Albuquerque, N. Mex. ATTN: Technical Training Group
181-189 Chief, Armed Forces Special Weapons Project, Washington 25, D.C. ATTN: Document Library Branch
190 Office of the Technical Director, Directorate of Effects Tests, Field Command, AFSWP, PO Box 577, Menlo Park, Calif. ATTN: Dr. E. B. Doll
191-197 Technical Information Service, Oak Ridge, Tenn. (Surplus)

ATOMIC ENERGY COMMISSION ACTIVITIES

198-200 U.S. Atomic Energy Commission, Classified Technical Library, 1901 Constitution Ave., Washington 25, D.C. ATTN: Mrs. J. M. O'Leary (For DMA)
201-203 Los Alamos Scientific Laboratory, Report Library, PO Box 1663, Los Alamos, N. Mex. ATTN: Helen Redman
204-208 Sandia Corporation, Classified Document Division, Sandia Base, Albuquerque, N. Mex. ATTN: Martin Lucero
209-211 University of California Radiation Laboratory, PO Box 808, Livermore, Calif. ATTN: Margaret Edlund
212 Weapon Data Section, Technical Information Service, Oak Ridge, Tenn.
213-270 Technical Information Service, Oak Ridge, Tenn. (Surplus)

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AEC, Oak Ridge, Tenn